

Cold fusion

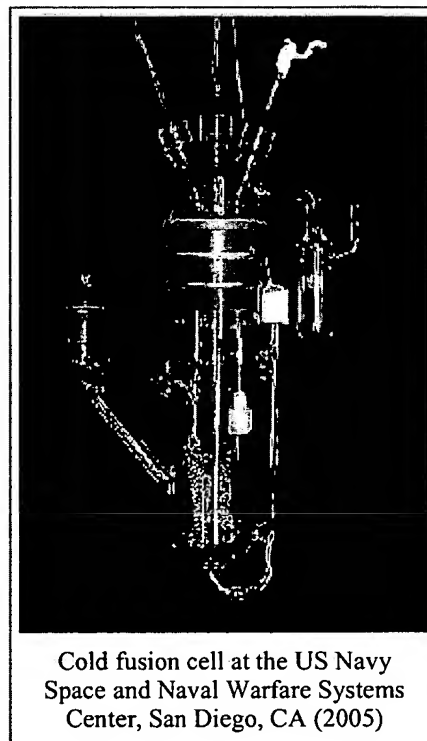
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By definition, **Cold fusion** is a nuclear fusion reaction that takes place at or near room temperature and normal pressure instead of the millions of degrees required for plasma fusion reactions.

Cold fusion is the popular term used to refer to what is now called "low energy nuclear reactions" (LENR), part of the field of "condensed matter nuclear science" (CMNS). The initial claim of such cold fusion was first reported by Martin Fleischmann and Stanley Pons at the University of Utah in March of 1989. This announcement was front-page news for some time, and generated a strong controversy, but the public debate abated quickly and cold fusion was generally rejected by the mainstream scientific community.^[1] However, from 1989 to the present many scientists report experimental observations of excess heat, nuclear transmutations, tritium, and helium. These experiments use a variety of methods.^{[2][3][4][5][6]}

The latest mainstream review of research in LENR occurred in 2004 when the US Department of Energy set up a panel of eighteen scientists. When asked "Is there compelling evidence for power that cannot be attributed to ordinary chemical or solid-state sources", the panelists were evenly split. When asked about low energy nuclear reactions, two thirds of the panel did not feel that there was any conclusive evidence, five found the evidence "somewhat convincing" and one was entirely convinced. The nearly unanimous opinion of the reviewers was that funding agencies should entertain individual, well-designed proposals for experiments in this field. Critics say that the DOE review had too limited a scope and inappropriate review process. ^{[7][8][9]}

The popular press sometimes use the term "cold fusion" to describe "globally cold, locally hot" plasma fusion that occurs in table-top apparatus such as pyroelectric fusion.^[10] Another form of cold fusion is muon-catalyzed fusion; unfortunately, the muons it uses require too much energy to create and have too short of a half-life to make the process practical for energy generation. Since both of these types of fusion are accepted as known-science processes and generate no controversy, neither pyroelectric fusion nor muon-catalyzed fusion are presented further in this article.



Cold fusion cell at the US Navy Space and Naval Warfare Systems Center, San Diego, CA (2005)

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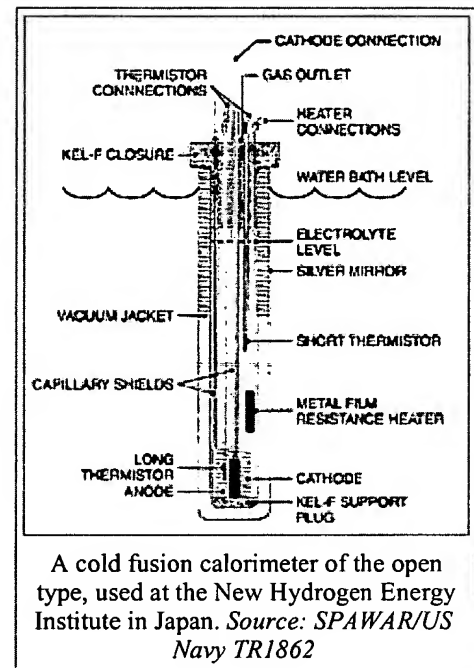
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Original Fleischmann and Pons claim

On March 23, 1989, the chemists Martin Fleischmann and Stanley Pons at the University of Utah spoke at a press conference held by the University of Utah and reported the production of excess heat that they say could only be explained by a nuclear process. The report was particularly astounding given the simplicity of the equipment: essentially an electrolysis cell containing heavy water (deuterium oxide) and a palladium cathode which rapidly absorbed the deuterium produced during electrolysis.

In their original set-up, Fleischmann and Pons used a Dewar flask (a double-walled vacuum flask) for the electrolysis, so that heat conduction would be minimal on the side and the bottom of the cell (only 5 % of heat lost in this experiment). The cell flask was then submerged in a bath maintained at constant temperature to eliminate the effect of external heat sources. They used an open cell, thus allowing the gaseous deuterium and oxygen resulting from the electrolysis reaction to leave the cell (with some heat too). It was necessary to replenish the cell with heavy water at regular intervals. The cell was tall and narrow, so that the bubbling action of the gas kept the electrolyte well mixed and of a uniform temperature. Special attention was paid to the purity of the palladium cathode and electrolyte to prevent the build-up of material on its surface, especially after long periods of operation.



The cell was also instrumented with a thermistor to measure the temperature of the electrolyte, and an electrical heater to generate pulses of heat and calibrate the heat loss due to the gas outlet. After calibration, it was possible to compute the heat generated by the reaction.

A constant current was applied to the cell continuously for many weeks, and heavy water was added as necessary. For most of the time, the power input to the cell was equal to the power that went out of the cell within measuring accuracy, and the cell temperature was stable at around 30 °C. But then, at some point (and in some of the experiments), the temperature rose suddenly to about 50 °C without changes in the input power, for durations of 2 days or more. The generated power was calculated to be about 20 times the input power during the power bursts, and, according to Fleischmann and Pons, could not be explained by chemical reactions. Eventually the power bursts in any one cell would no longer occur and the cell was turned off.

History of cold fusion by electrolysis

Main article: Cold fusion history

The special ability of palladium to absorb hydrogen was recognized in the nineteenth century. In 1927, Swedish scientist J. Tandberg said that he had fused hydrogen into helium in an electrolytic cell with palladium electrodes, but his patent application was eventually denied.

In the 60's, Fleischmann and his team started investigating the possibility that chemical means could influence nuclear processes, and that quantum electrodynamics could be better than quantum mechanics to describe such processes.^[11] Experimental evidences lead Fleischmann and Pons to work on electrolysis experiments with their own funds from 1984 on. In 1988, they applied to the US Department of Energy for funding for a larger series of experiments. Their application was reviewed by several scientists, including Steven E. Jones of Brigham Young University, who had already started investigating cold nuclear fusion. Both teams met on several occasions to discuss sharing work and techniques, but as they were getting ready to publish their results in early 1989, the collaboration turned into rivalry and, eventually, dispute.

Fleischmann and Pons held a press conference on March 23, 1989, to present their results and claimed excess heat that could not be explained by chemical reactions. This claim had not gone through the scrutiny of peer review, and some accused them of doing "*science by press release*". On April 10, they published their 8-page "preliminary note" in the Journal of Electroanalytical Chemistry. It was rushed, very incomplete and contained a clear error with regard to the gamma spectra.

According to Fleischmann, he and Pons found themselves pressured by the administration of the University of Utah to go forward with the press conference that ended up destroying their careers.^[12] They were rushed against their better judgement by university politics to be the first to come out with the discovery. Fleischmann lamented that the university's interest in patents and grants were more important than proper scientific protocol. In an April 2004 letter, Fleischmann wrote: "I was not at all in favour of the high publicity route adopted by the University of Utah and wanted to delay consideration of publication until September 1990." The university required that he "had to appear supportive of their position."

According to Chase Peterson, then the president of the University of Utah, "The decision to announce was Martin and Stan's, then the University stepped in to help. It is quite possible that Martin did get cold feet but no one in the University ever heard from him that the announcement should be cancelled." ^[13]

The press conference attracted much media attention, and many scientists attempted to repeat the experiments; many failed, and physicists started to challenge the claim publicly. In July and November 1989, Nature published papers critical of cold fusion. In November, a special panel formed by the Energy Research Advisory Board (under a charge of the US Department of Energy) reported the result of their investigation into cold fusion. The scientists in the panel found the evidence for cold fusion to be unconvincing, and their report was widely published. Cold fusion became a pariah science rejected by the scientific establishment.

The 1990s saw little cold fusion research in the United States, and much of the research during this time period occurred in Europe and Asia. By 1991, 92 groups of researchers from 10 different countries had reported excess heat, tritium, neutrons or other nuclear effects. Researchers share their results at the International Conference on Cold Fusion, and publish papers in specialized peer reviewed journals such as Physical Review A, Journal of Electroanalytical Chemistry, Japanese Journal of Applied Physics, and Journal of Fusion Energy.

2004 Department of Energy Review

Main article: 2004 DoE panel on cold fusion

In 2004, the United States Department of Energy (USDOE) decided to take another look at cold fusion to

determine if their policies towards cold fusion should be altered due to new experimental evidence. They set up a panel on cold fusion. Its 18 reviewers were split approximately evenly on the issue "Is there compelling evidence for power that cannot be attributed to ordinary chemical or solid states sources", a significant change compared to the 1989 DoE panel. However, several of those who judged that there was unexplained power did not believe that a nuclear reaction had been shown to be the source: two-thirds of the reviewers did not feel that the evidence was conclusive for low energy nuclear reaction, one found the evidence convincing, and the remainder indicated that they were somewhat convinced. Many reviewers noted that poor experiment design, documentation, background control and other similar issues hampered the understanding and interpretation of the results presented. The nearly unanimous opinion of the reviewers was that funding agencies should entertain individual, well-designed proposals for experiments in this field.^[14]

However, cold fusion researchers say that the DOE review was limited in scope, by request of the DOE. Only experimental evidences related to the original F&P claims of excess heat and Jones claims of radiations were reviewed.^{[15][16]} Thus nuclear transmutations and other topics were not reviewed, although a single comment was made about nuclear transmutations. Furthermore, the reviewers were not active in the fields, did not know of its key experiments and were ignorant of its literature.^[17] Their detailed responses showed lack of interest and had serious flaws in their justification.^{[18][19]}

Possible commercial developments

Cold fusion researchers say that it could have a substantial economic impact, and help resolve global issues such as global warming or the risk of energy crisis. It could have advantages over plasma fusion (which has also not yet been developed for practical application) because it produces little ionizing radiation and can be scaled to small devices.^[20]

Cold fusion's commercial viability is unknown. The evidences of the excess heat effect are not accepted by a majority of scientists. If it exists, the effect would have to be thoroughly controlled before it could be safely scaled up to larger size for commercialization. Cells are orders-of-magnitude too small to be commercially viable (with typically less than a gram of material).^[21] Researchers have not yet discovered methods to prevent cathodes from deteriorating, cracking, and melting during the experiments. Additionally, all cold fusion experiments have produced power in bursts lasting for days or weeks, not for months as is needed for many commercial applications.

Skeptics say that commercial applications have been promised many times but never delivered.^[22] In 1995, Clean Energy Technology, Inc (CETI) demonstrated a 1-kilowatt cold fusion reactor at the Power-Gen '95 Americas power industry trade show in Anaheim, CA. They obtained several patents from the USPTO.^{[23][24]} As of 2006, no cold fusion reactor has been commercialized by CETI or the patent holders.

Companies publicly claiming to be developing cold fusion devices, include: Energetics Technologies Ltd. (Israel), D2Fusion (<http://www.d2fusion.com/>), JET Thermal Products (<http://world.std.com/~mica/jet.html>), Clean Energy Technologies, Inc. of Sarasota Florida (CETI), and ENECO of Salt Lake City.^[25] Ongoing developments concerning cold fusion commercialization efforts are tracked at peswiki (http://peswiki.com/index.php/PowerPedia:Cold_fusion#Ongoing_developments). There are also some private cold fusion commercialization efforts that are rumored to be ongoing.^[26]

Arguments in the controversy

See also: 2004 DoE panel on cold fusion, cold fusion controversy

Theoretical possibility of fusion at low temperature

Cold fusion's most significant problem in the eyes of many scientists is that current theories describing nuclear fusion can not explain how a cold fusion reaction could occur at relatively low temperatures, and that there is currently no accepted theory to explain cold fusion.^{[27][28]}

In order for fusion to occur, the electrostatic force (Coulomb repulsion) that repels the positively charged nuclei must be overcome. Once the distance between the nuclei becomes comparable to one femtometre, the attractive strong interaction takes over and the fusion may occur. However, bringing the nuclei so close together requires an energy on the order of 10 MeV per nucleus, whereas the energies of chemical reactions are on the order of several electron-volts; it is hard to explain where the required energy would come from in room-temperature matter. Nuclei are so far apart in a metal lattice that it is hard to believe that the distant atoms could somehow facilitate the fusion reaction: the deuterium nuclei are further apart in a palladium cathode than in a molecule of heavy water. Moreover, when fusion occurs, a large amount of energy is normally released as gamma rays or energetic protons or neutrons: there is no known mechanism that would release this energy as heat within the relatively small metal lattice.^[29] Robert F. Heeter said that the direct conversion of fusion energy into heat is not possible because of energy and momentum conservation and the laws of special relativity.^[30] Other critics say that until the observations are satisfactorily explained, there is no reason to believe that the effects have a nuclear rather than a non-nuclear origin.^[31]

Huizenga, who was the head of the DoE ERAB panel that dismissed cold fusion in 1989, concluded:^[32]

"If the claimed excess heat exceeds that possible by other conventional processes (chemical, mechanical, etc.), one must conclude that an error has been made in measuring the excess heat."

However, Steven Jones, a cold fusion skeptic, has observed anomalous neutron emissions from electrolytic cells, and said that they result from fusion reactions unexplained by current theories (but 10 orders of magnitude lower than what would be required to explain the excess heat of Fleischmann and Pons), and his claim has never been challenged nor retracted, but confirmed by other researchers.^{[33][34]}

Cold fusion researchers have proposed several theoretical hypotheses to explain the effect (see low energy nuclear reaction), while there are partial theories, no complete theory has been found that explains all the experimental results.

One such theory is based on resonant tunneling. Quantum tunneling is an accepted effect by which the Coulomb barrier can be "tunneled through", but it predicts a rate of cold fusion well below what is claimed in F&P experiments. Resonant tunneling is based on the proposition that the metal lattice can amplify this effect through resonance.^[35]

At the quantum mechanics level both energy and matter can behave as particles or waves. There can also be coherent behavior in matter as in super conductivity and superfluidity. Giuliano Preparata, a high energy physicist, argued in his book on QED (quantum electrodynamics) coherence in matter that cold fusion phenomena could be explained by QED. Fleischmann and other cold fusion scientists think that QED can provide a solution.^{[36][37]}

Nobel laureate Julian Schwinger received his prize for being one of the developers of QED. He believed that "If a proven track record can be established... you have to believe it". He also believed that cold fusion does not violate conventional theory. As he put it, "The defense [of cold fusion] is simply stated: The circumstances of cold fusion are not those of hot fusion".^[38]

Beaudette points out that just because an experimental result cannot be explained by existing theory does not mean the result is invalid. He offers the example of the heat from the radioactivity of radium discovered in 1903 by Pierre Curie. According to Marie Curie "More striking still was the discovery of the discharge of heat from

radium. Without any alteration of appearance this substance releases each hour a quantity of heat sufficient to melt its own weight of ice. This defied all contemporary scientific experience." Beaudette also gives the example of superconductivity which required forty seven years to develop a theory.^[39]

Nuclear Transmutations

Nuclear transmutations have been reported in many cold fusion experiments since 1992. These reactions (which may be a nuclear fusion or nuclear fission reaction) result in the transformation of a chemical element into another. If one accepts that nuclear transmutations are in fact observed in these experiments, he would have to accept that nuclear reactions take place in cold fusion experiments. He would also have to accept that an apparently enormous Coulomb barrier can be overcome, and that the released energy can be converted to heat.

Tadahiko Mizuno is a prominent nuclear transmutation experimenter, and was among the first to contribute several papers and a book on the subject.^{[40][41]}

Nuclear transmutation experiments have been reviewed by Dr. Miley.^[42], a recognized researcher in "Hot Fusion" for his contributions to Inertial electrostatic confinement. ^[43] He reports that several dozen laboratories are studying these effects. Some experiments result in the creation of only a few elements, while others result in a wide variety of elements from the periodic table. Calcium, copper, zinc, and iron were the most commonly reported elements. Lanthanides were also found: this is significant since they are unlikely to enter as impurities. In addition, the isotopic ratios of the observed elements differ from their natural isotopic ratio or natural abundance. Many elements have multiple isotopes and the percentages of the different isotopes are constant on earth within one tenth of one percent. In general it requires gaseous diffusion, thermal diffusion, electromagnetic separation or other exotic processes of isotope separation or a nuclear reaction to change an element from its natural isotope ratio. The presence of an unnatural isotope ratio makes contamination an implausible explanation. Some experiments reported both transmutations and excess heat, but the correlation between the two effects has not been established. Radiations have also been reported. Miley also reviews possible theories to explain these observations. ^[44]

So far the clearest evidence for transmutation has come from an experiment made by Iwamura and associates, and published in 2002 in the Japanese Journal of Applied Physics (one of the top physics journals in Japan).^[45] Instead of using electrolysis, they forced deuterium gas to permeate through a thin layer of caesium (also known as cesium) deposited on calcium oxide and palladium, while periodically analyzing the nature of the surface through X-ray photoelectron spectroscopy. As the deuterium gas permeated over a period of a week, the amount of caesium progressively decreased while the amount of praseodymium increased, so that caesium appeared to be transmuted into praseodymium. When caesium was replaced by strontium, it was transmuted into molybdenum with anomalous isotopic composition. In both cases this represents an addition of four deuterium nuclei to the original element. They have produced these results six times, and reproducibility was good. The energy released by these transmutations was too low to be observed as heat. No gamma rays were observed. When the calcium oxide was removed or when the deuterium gas was replaced by hydrogen, no transmutation was observed. The authors analyzed, and then rejected, the possibility to explain these various observations by contaminations or migration of impurities from the palladium interior. The experiment was replicated by researchers from Osaka University using Inductively Coupled Plasma Mass Spectrometry to analyze the nature of the surface (the Pd complex samples were provided by Iwamura).^[46]

In later similar experiments by Iwamura Barium 138 was transmuted to Samarium 150 and Barium 137 was transmuted into Samarium 149. The Barium 138 experiment used a natural isotope ratio of Barium. The Barium 137 experiment used a Barium 137 enriched isotope ratio. These transmutations represent an addition of six deuterium nuclei.^[47]

While recognizing the quality of the experiment, a 2004 DOE panelist said that, from a nuclear physics

perspective, such conclusions of transmutations are "not to be believed". Fusing 2 deuterons is difficult enough; merging four deuterons with a heavy nucleus such as Palladium [*sic*] is not to be believed, especially when no evidence is presented for any nuclear products with intermediate atomic mass such as Yttrium, Zirconium, and Niobium. The panelist suggested that the observation could be explained by the migration of the anomalous elements from the interior of the Palladium. [48].

Cold fusion researchers responded that such migration is not possible:

1. Deuterium atoms, flowing from the surface to the interior, would cause diffusion of the anomalous element away from the surface, not toward the surface.
2. Mass spectroscopy done at various depths shows that the anomalous element was not present in the palladium.
3. The element that was originally on the surface disappears at the same rate as the anomalous element appears.
4. The isotopes of the anomalous element are unnatural, and the isotope shifts are exactly what are expected should the missing element transmute into the new element

They say that, since the initial element disappears, the "migration explanation" would imply that the element applied to the surface migrates toward the interior, while the anomalous element migrates in the opposite direction toward the surface. This would violate as many expected behaviors as does cold fusion but in a different field of science: therefore, the Iwamura results justify additional research to understand what's happening. They also said such explanations are mere hand waving, and that this kind of reasoning is typical of most reviews. [49]

Bush and Eagleton have reported the appearance of radioactive isotopes with an average half-life of 3.8 days in electrolytic cells, an observation that is difficult to explain by contamination or migration. [50]

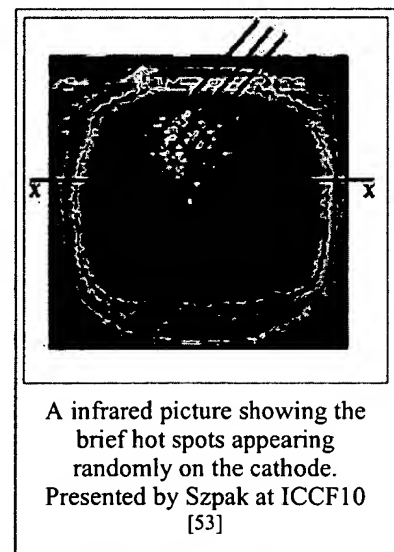
Attempts to find at least partial theoretical explanations are being made by Takahashi and others. One proposal by Takahashi to explain the wide range of elements generated is that fission of palladium is initiated by high energy photons, and suggests potential applications in the treatment of nuclear wastes by transmutation. [51][52]

Measurement of excess heat

Excess heat production is an important characteristic of the effect that has created much criticism. A review of excess heat experiments by Beaudette showed power outputs ranging from 15 milliwatts to 205 watts. [54] A variety of calorimetric devices have been used: isoperibolic, flow, and Seebeck. [55]

The cold fusion researchers presenting their review document to the 2004 DoE panel on cold fusion said that the possibility of calorimetric errors has been carefully considered, studied, tested and ultimately rejected by cold fusion researchers. They explain that, in 1989, Fleischmann and Pons used an open cell from which energy was lost in a variety of ways: the differential equation used to determine excess energy was awkward and subject to misunderstanding, and the method had an error of 1% or less. Recognizing these issues, SRI International and other research teams used a flow calorimeter around closed cells: the governing equations become trivial, and the method has an error of 0.5 % or better. Over 50 experiments conducted by SRI International showed excess power well above the accuracy of measurement. Arata and Zhang have observed excess heat power averaging

80 watts over 12 days. Their control experiments using light water never showed excess heat. [56] While Storms says that light water is an impurity that can kill the effect [57], Miley and others have reported low energy nuclear



A infrared picture showing the brief hot spots appearing randomly on the cathode. Presented by Szpak at ICCF10 [53]

reactions with light water. [58]

However, many reviewers in the panel noted that poor experiment design, documentation, background control and other similar issues hampered the understanding and interpretation of the results presented to the DoE panel. The reviewers who did not find the production of excess power convincing said that all possible chemical and solid state causes of excess heat have not been investigated and eliminated as an explanation, that the magnitude of the effect has not increased in over a decade of work, or that production over a period of time is a few percent of the external power applied and hence calibration and systematic effects could account for the purported effect.

Other evidences of heat generation not reviewed by the DOE include the detection of hot spots by infra-red (see picture), the detection of mini-explosions by a piezo-electric substrate, and the observation of discrete sites exhibiting molten-like features that require substantial energy expenditure. [59][60]

In 2005, Shanahan raised questions about the consequences of imperfect stirring of the electrolyte on the calibration of calorimeters before and during cold fusion experiments, and hence on the measurement of excess heat. [61] They were addressed by Storms in a paper published in *Thermochim. Acta*, but a rebuttal was published. [62][63]

Some large quantity of heat events have been reported. In the late fall of 1984 Fleischmann and Pons were conducting an experiment that ran for several months using a one cubic centimeter of palladium cathode. When they came in to the lab one morning they found that "a substantial portion of the palladium fused (melting point 1,554 degrees Celsius), part of it vaporized, and the cell and the contents and a part of the fume cupboard housing the experiment were destroyed." There was also a one foot hole in the lab bench and a pit in the concrete floor up to four inches deep. This incident convinced Fleischmann and Pons that they were on the right track. [64] [65]

On April 22, 1991 Mizuno turned off electrolysis on a cell with a 100 gram palladium cathode. The cell was still producing heat with out input power in the so called "heat after death" phenomena. The cell was placed in a bucket of water. Water was replaced as it was evaporated. In all 37.5 liters of water were evaporated over a ten day period. This is equivalent to 85 megajoules or 23.6 kilowatt hours of energy. Alternatively enough energy to run a 31.7 horsepower engine for an hour. [66]

Energy source versus power store

It has been suggested that the observed excess power output which begins after a cell is operated for a long time may be due to energy accumulated in the cell during operation. This would require a systematic error in calorimetry (in other words that the cell is drawing more power than goes out, but calorimetry incorrectly shows the two to be equal), or a very slow accumulation of energy below the heat measurement accuracy during prolonged loading of the cell.

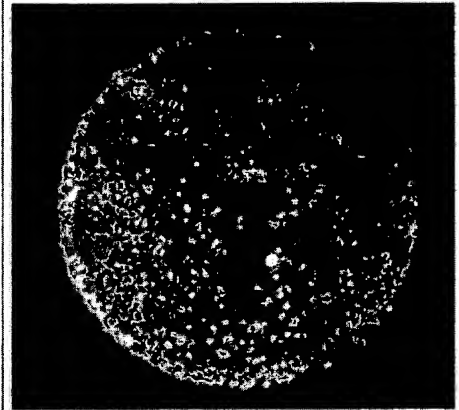
The cold fusion researchers presenting their review document to the 2004 DoE panel on cold fusion said that the amount of energy reported in some of the experiments appears to be too great compared to the small mass of material in the cell, for it to be stored by any known chemical process. [67] The energy released by electrolytic cells after all energy input are removed, in so-called "heat after death" experiments, are 2 or 3 orders of magnitude greater than what any chemical storage mechanism would allow. [68] Of course, this in itself would be quite useful.

Relation between excess heat and nuclear products

For a nuclear reaction to be proposed as the source of energy, research must show that the amount of energy is related to the amount of nuclear products.

If the excess heat were generated by the hot fusion of two deuterium atoms, the most probable outcome, according to current theory, would be the generation of either a tritium and a proton, or a ^3He and a neutron. The level of protons, tritium, neutrons and ^3He actually observed in Fleischmann-Pons experiment have been higher than current theory asserts, but well below the level expected in view of the heat generated, implying that these reactions cannot explain it.

If the excess heat were generated by the hot fusion of two deuterium atoms into ^4He , a reaction which is normally extremely rare, ^4He and gamma rays would be generated. Miles et al. reported that ^4He was indeed generated in quantity consistent with the excess heat, but no studies have shown levels of gamma rays consistent with the excess heat.^[70] Current nuclear theory cannot explain these results, and the statement "the heat comes from a nuclear source" remains a hypothesis. Researchers are puzzled that some experiments produce heat without ^4He .^[71] Critics note that great care must be used to prevent contamination by helium naturally present in atmospheric air.^[72]



An autoradiograph showing X-rays from tritium in a cold fusion experiment at the Neutron Physics Division, Bhabha Atomic Research Centre, Bombay, India^[69]

Excess Helium is very hard to detect in controlled experiments. It is like hydrogen one of the smallest atoms. Helium can thus leak through and permeate many substances. It exists in the atmosphere at 5.22 parts per million. Helium-4 has essentially the same mass as the D_2 molecule, and helium-3 has essentially the same mass as the DH molecule.

The summary document presented to the DOE 2004 reviewers made several statements about helium-4 and heat. The nuclear reaction $\text{D} + \text{D} = \text{He} + 23.4 \text{ MeV}$ (Million electronvolts) is thought to be the primary source of heat. Helium-4 has been found in the gas phase, dissolved in the cathode metal, and emitted as charged particles. In an experiment by Gozzi bursts of excess energy were time-correlated with bursts of helium-4 in the gas stream.^[73] A review of experiments by Miles, Bush, McKubre, and Gozzi resulted in the following conclusions.

1. The rate of helium production increases linearly with excess power.
2. The amount of helium observed in the gas stream varied from .25 to 1.0 the amount expected from the $\text{D} + \text{D} = \text{He} + 23.4 \text{ MeV}$ reaction.
3. Helium is partially retained in the cathode and only slowly released to the gas phase.

An experiment was performed to see how much driving all the retained helium-4 out of the cathode improved the helium-4 to heat correlation. The result was $1.04 \pm 10\%$ for the reaction $\text{D} + \text{D} = \text{He} + 23.4 \text{ MeV}$. This was at the time of the report the most accurately determined result. However it could be argued that since the helium-4 measured was less than half the concentration in air helium-4 might have leaked in from the atmosphere. Other experiments have produced helium-4 levels above that in air and support the idea that the helium-4 is a reaction product.^[74]

Although there appears to be evidence of transmutations and isotope shifts near the cathode surface in some experiments, cold fusion researchers generally consider that these anomalies are not the ash associated with the primary excess heat effect.^[75]

Reproducibility of the result

While some scientists have reported to have reproduced the excess heat with similar or different set-ups, they

could not do so with predictable results, and many others failed. Some see this as a proof that the cold fusion is pseudoscience, or more precisely, pathological science.

Yet, the 1989 DOE panel said: "Even a single short but valid cold fusion period would be revolutionary. As a result, it is difficult convincingly to resolve all cold fusion claims since, for example, any good experiment that fails to find cold fusion can be discounted as merely not working for unknown reasons."^[76]

Nobel Laureate Julian Schwinger said that it is not uncommon to have difficulty in reproducing a new phenomenon that involves an ill-understood macroscopic control of a microscopic mechanism. As examples, he gave the onset of microchip studies, and the discovery of high temperature superconductivity.^[77]

The cold fusion researchers presenting their review document to the 2004 DoE panel on cold fusion said that the observation of excess heat has been reproduced, that it can be reproduced at will when the proper conditions are reproduced, and that many of the reasons for failure to reproduce it have been discovered. Yet, a DOE reviewer said: "There are conflicting claims amongst the advocates, and inconsistencies amongst seemingly similar experiments"; another reviewer concurred.^{[78][79]}

Suppression of cold fusion research

In June 1990, Gary Taubes, a science writer who has written two books and several articles investigating allegations of fraudulent activity in science, published an article in *Science* clearly suggesting that researchers at Texas A&M had added tritium to fake their results. After multiple investigations, the university found no evidence of fraud or incompetence. John Bockris, who was then a distinguished professor in physical chemistry at Texas A&M University and a cofounder of the International Society for Electrochemistry, had to appeal to the American Association of University Professors before the harassment stopped.^[80]

In 1991, Dr. Eugene Mallove said that the negative report issued by MIT's Plasma Fusion Center in 1989, which was highly influential in the controversy, was fraudulent because data was shifted ^[81] without explanation, and as a consequence, this action obscured a possible positive excess heat result at MIT. In protest of MIT's failure to discuss and acknowledge the significance of this data shift, he resigned from his post of chief science writer at the MIT News office on June 7, 1991. He maintained that the data shift was biased to both support the conventional belief in the non-existence of the cold fusion effect as well as to protect the financial interests of the plasma fusion center's research in hot fusion. ^[82]

Cold fusion researchers claim that cold fusion is suppressed, and that skeptics suffer from pathological disbelief.^[83] They say that there is virtually no possibility for funding in cold fusion in the United States, and no possibility of getting published.^[84] They say that people in universities refuse to work on it because they would be ridiculed by their colleagues.^[85]

Nobel Laureate Julian Schwinger said that he had experienced "the pressure for conformity in editor's rejection of submitted papers, based on venomous criticism of anonymous reviewers. The replacement of impartial reviewing by censorship will be the death of science".^[86] He resigned as Member and Fellow of the American Physical Society, in protest of its peer review practice on cold fusion.

See also

- 2004 DoE panel on cold fusion
- Timeline of cold fusion
- Martin Fleischmann
- Stanley Pons
- Mizuno experiment

- Cold fusion controversy
- Low energy nuclear reaction
- Biological transmutation
- Pathological science
- pathological disbelief
- Huemul Project

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Further reading

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- U.S. Navy Report Detailing a Decade of Cold Fusion Research (<http://www.infinite-energy.com/iemagazine/issue44/navy.html>) "Thermal and Nuclear Aspects of the Pd/D2O System", U.S. Navy TECHNICAL REPORT 1862, February 2002
- U.S. DoE 2004 Cold Fusion Review (http://www.science.doe.gov/Sub/Newsroom/News_Releases/DOE-SC/2004/low_energy/index.htm) - U.S. Department of Energy review of 15 years of cold fusion experiments
 - Additional information on the DoE 2004 Cold Fusion Review. (<http://lenr-canr.org/Collections/DoeReview.htm>) This page includes the full text of the reviewer's comments, which is not available on the DoE pages, plus links to the full text of 42 of the papers submitted by cold fusion researchers to the review panel. (The list of all 130 submitted papers can be found here (<http://lenr-canr.org/acrobat/Hagelsteinnewphysica.pdf>).)
 - A response to the review of cold fusion by DOE (<http://lenr-canr.org/acrobat/StormsEaresponset.pdf>) - by Edmund Storms
 - Response to the DoE/2004 Review of Cold-Fusion Research (<http://www.lenr-canr.org/acrobat/BeaudetteCresponseto.pdf>) - C. Beaudette's critique of the DoE 2004 Cold Fusion Review
- Cold Fusion - An Objective Assessment (<http://www.tcm.phy.cam.ac.uk/~bdj10/papers/storms/review8.html>) - by Dr. Edmund Storms, a review of the experimental results (December 2001; 233 references, including 34 studies reporting anomalous energy using the Pons-Fleischmann method)
- A Student's Guide to Cold Fusion (<http://lenr-canr.org/acrobat/StormsEastudentsg.pdf>) - by Edmund Storms. A 55-page introduction to the subject.
- Overview of BARC Studies in Cold Fusion. (<http://lenr-canr.org/acrobat/IyengarPKoverviewof.pdf>) - P.K. Iyengar (Atomic Energy Commission, India) and M. Srinivasan (Bhabha Atomic Research Centre) review some of the major research in India.
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Journals and publications

- *Infinite Energy* (<http://www.infinite-energy.com/>) - one of the original periodicals dedicated to cold fusion and new energy
- *New Energy Times* (<http://www.newenergytimes.com/>) - site that focuses on the latest advances in the field of cold fusion
- *Cold Fusion Times* (<http://world.std.com/~mica/cft.html>) - quarterly journal about cold fusion

Websites and repositories

- The International Society for Condensed Matter Nuclear Science (<http://www.iscmns.org/>)
- Recent papers on cold fusion (<http://newenergytimes.com/Reports/SelectedPapers.htm>) listed on New Energy Times
- LENR-CANR Low Energy Nuclear Reactions — Chemically Assisted Nuclear Reactions (<http://www.lenr-canr.org/>) - information and links on cold fusion research (mainly pro-cold fusion), and an online library of over 500 full-text papers from the peer-reviewed literature and conference proceedings
- Britz's cold nuclear fusion bibliography (<http://www.chem.au.dk/~db/fusion/>) - an overview and review of almost all available publications about cold nuclear fusion

- Cold Fusion — 17 Years and Heating Up (<http://freeenergynews.com/Directory/ColdFusion/>) - directory of cold fusion resources compiled by *FreeEnergyNews.com*
- L. Kowalski's web site (<http://blake.montclair.edu/~kowalskil/cf/>) - a collection of commentaries on cold fusion research from a physics teacher
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- Cold Fusion overview (http://peswiki.com/index.php/PowerPedia:Cold_fusion) - John Coviello provides an introductory synopsis for new encyclopedic entry at *PESWiki.com*.
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Fusion power

Atomic nucleus | Nuclear fusion | Nuclear power | Nuclear reactor | Timeline of nuclear fusion
 Plasma physics | Magnetohydrodynamics | Neutron flux | Fusion energy gain factor | Lawson criterion

Methods of fusing nuclei

- **Magnetic confinement:** Tokamak - Spheromak - Stellarator - Reversed field pinch - Field-Reversed Configuration - Levitated Dipole
- **Inertial confinement:** Laser driven - Z-pinch - Bubble fusion - Farnsworth–Hirsch Fusor - Pyroelectric fusion
 - **Cold fusion:** Muon-catalyzed fusion

List of fusion experiments

Magnetic confinement devices

ITER (*International*) | JET (*European*) | JT-60 (*Japan*) | Large Helical Device (*Japan*) | KSTAR (*Korea*) | EAST (*China*) | T-15 (*Russia*) | DIII-D (*USA*) | TFTR (*USA*) | NSTX (*USA*) | NCSX (*USA*) | Alcator C-Mod (*USA*) | LDX (*USA*) | PACER (*USA*) | H-1NF (*Australia*) | MAST (*UK*) | START (*UK*) | DEMO (*Commercial*)

Inertial confinement devices

NIF (*USA*) | **LMJ** (*France*) | Nova laser (*USA*) | OMEGA laser (*USA*) | Shiva laser (*USA*) | Z machine (*USA*)

See also: International Fusion Materials Irradiation Facility

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